EXHIBIT B

FM Unimpaired Audio Quality Report

Fourth Report
to the
National Radio Systems Committee

FM IBOC DAB
Unimpaired Audio Quality Test

February 19, 2002

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This fourth report to the National Radio Systems Committee ("NRSC") contains results from the unimpaired audio quality test for iBiquity Digital Corporation's ("iBiquity") FM IBOC DAB system. It is a supplement to iBiquity's first three reports detailing test results on the FM and AM IBOC systems. This test was designed to assess the audio quality of FM IBOC in unimpaired RF channel conditions using Generation 2 hardware and iBiquity's audio compression technology.

The FM unimpaired audio quality test was designed to assess the quality of the FM IBOC system against both a CD reference and the highest possible quality FM analog. As is described in greater detail herein, in all cases FM IBOC outscored the best quality analog FM. In addition, the test results confirmed that FM IBOC provides CD-quality sound. Based on these results, the NRSC can conclude FM IBOC will provide a significant improvement in audio quality over that offered by analog FM broadcasting.

I. Introduction

The unimpaired audio quality test was conducted using iBiquity's Generation 2 hardware incorporating iBiquity's audio compression technology. The tests were designed to compare audio recordings from a CD source, FM IBOC and the four NRSC analog FM receivers. The test audio samples were transmitted over an unimpaired laboratory test channel through the FM IBOC system and through the analog FM system using each of the four analog receivers. All recordings were made at the ATTC,[1] and the sound samples were sent to Dynastat for subjective evaluation. The subjective evaluation used the same facilities, ACRM methodology, and general population listeners as were used for the impaired testing conducted in 2001.[2] For this test, the NRSC agreed that the ACRM methodology should be modified to elicit a more critical audio quality assessment than achieved in earlier tests. The three refinements to the methodology were:

1. The test used as source audio the eighteen samples the NRSC DAB Subcommittee's Test Audio Selection Ad-Hoc Group had defined as challenging for both IBOC audio compression technology and analog transmission.
2. The CD-quality source audio for each audio sample was included in the subjective test.
3. At the beginning of the audio evaluation experiment, each subject received training on the types of impairments he or she would experience.

II. Results

The comparison of audio samples from the CD source, FM IBOC and the highest possible quality analog demonstrated that FM IBOC provides a significant improvement in audio quality over that offered by analog FM. The test also showed that this improved

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[1] The ATTC procedures and results are set out in greater detail in Appendices B and C, respectively.

[2] A full report on the procedures and facilities used at Dynastat is provided in Appendix D.

audio quality from the IBOC system is equal to or better than CD-quality. As is shown in Figure 1 below, the average MOS scores for IBOC equaled those of the CD and exceeded those of all four analog receivers.

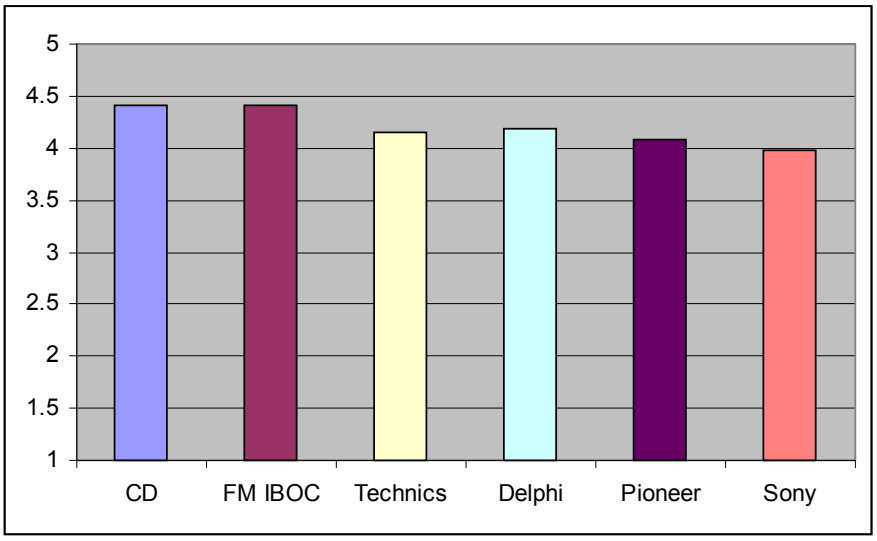

Figure 1 – Average Audio Quality MOS Scores for All Receivers

Figure 2 below shows that when analyzed by genre, FM IBOC also scored above analog and close to or better than the CD source. This result occurred with a variety of audio sources including Classical, Jazz, Rock, Instrumentals and Speech. The results were consistent with all types of audio.[3]

[3] Appendix E contains the MOS scores for each audio sample tested.

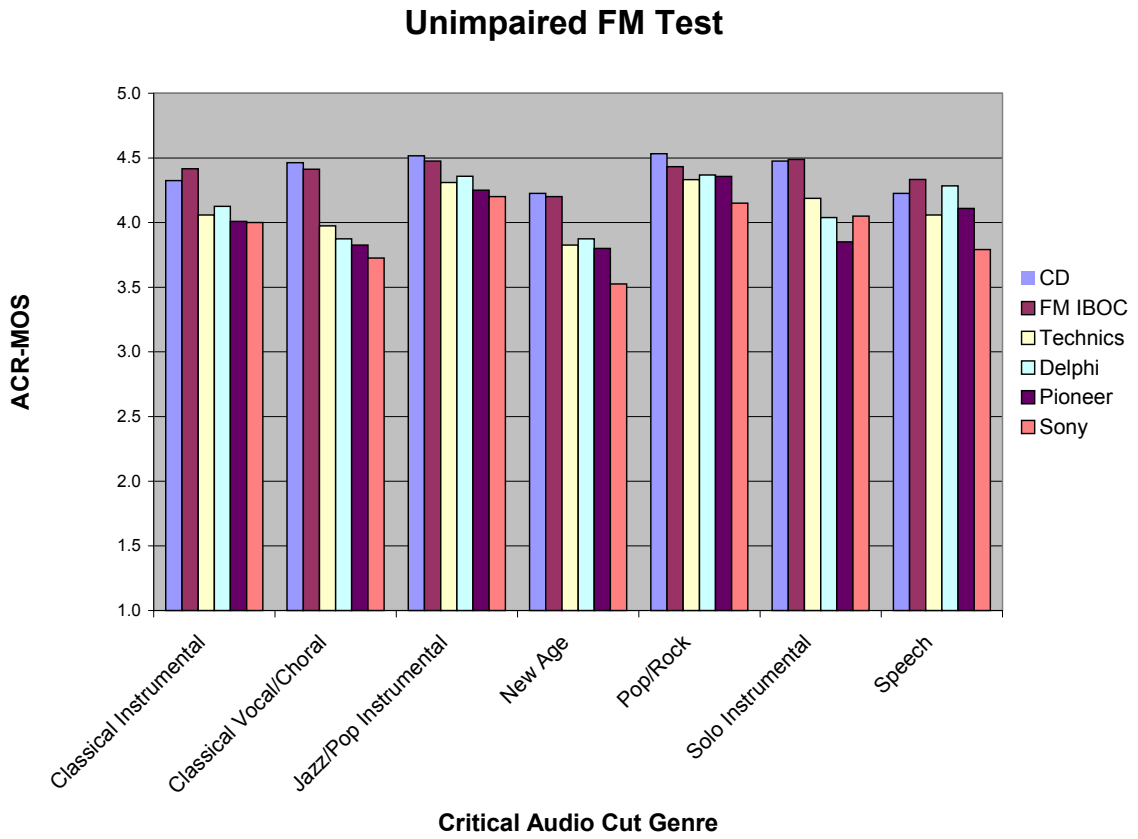

Figure 2 – Audio Quality Results by Genre

In order to gain greater insight into the results of these tests, iBiquity conducted an additional statistical analysis. This analysis used established statistical tools for analyzing the data in order to increase the precision of differential comparisons and allow conclusions to be reached with a high degree of confidence. The average MOS scores for each audio sample of the FM IBOC system were compared to the corresponding sample for each of the CD reference and the Delphi, Pioneer, Technics, and Sony receivers in order to statistically determine for each sample whether the FM IBOC system is equivalent to, better than or worse than the other sources. This analysis of the results indicated that the MOS rating of the FM IBOC system is statistically equivalent to that of the CD reference for 17 audio samples and worse for one sample. Thus, one may confidently infer from the data that the FM IBOC system is equivalent in quality to the high fidelity CD reference.[4]

III. Conclusions

This report describes the results of the NRSC Unimpaired Audio Quality testing of iBiquity's FM IBOC DAB transmission system incorporating iBiquity's digital audio compression technology. Through the use of critical subjective evaluation techniques,

[4] Details on this statistical analysis are contained in Appendix F.

these tests prove that trained listeners judge the quality of FM IBOC audio transmission equal to that of CD-source audio and superior to the best quality analog FM transmission. This conclusion, along with those from iBiquity's First Report to the NRSC, creates a compelling argument for the adoption of FM IBOC as the Digital Audio Broadcasting standard for the United States.

List of Appendices

Appendix A

Selection of Critical Audio Samples

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To: **Andy Laird, Chairman of Test Procedures Working Group**

From: **Ellyn G. Sheffield**

Date: **November 17, 2000**

Re: **Recommended Sound Samples from the Test Audio Selection Ad-Hoc Group**

Test Audio Selection Ad-Hoc Group
Tim J. Carroll
Frank Foti
David Maxson
Ellyn Sheffield
Emil Torick
Greg Nease, Moderator

This memorandum describes the process of selecting sound cuts for NRSC IBOC-DAB testing. **Attachment 1** is the recommended list of sound samples, including general descriptions of the source material and how they were ranked.

Sound Sample Pool

Sound samples were submitted for evaluation by Ellyn Sheffield on behalf of Ibiquity Digital Corp., Tim Carroll on behalf of Dolby Laboratories, Inc., and Ralph Justice. Forty-eight (48) musical samples and 2 speech samples were submitted, reviewed and evaluated (**Attachment 2** is a full listing of submissions). At the request of iBiquity during the meeting, Dolby recommended 2 additional sources to locate appropriate speech samples. These samples are not included in this evaluation, but will be transmitted to the NRSC under separate cover.

Evaluating Sound Samples

Evaluations were made as follows:

1. Samples were processed through PAC at 64 kbits/sec. In the beginning of the listening session, all samples were played once to afford committee members the opportunity to hear all samples they would be judging.
2. Originally it was agreed that samples would be rated on a 3-point scale (Low, Medium or High) depending on how rigorously they stressed the digital coder. After listening to several selections, it became clear that this scale did not afford enough resolution and Low-Medium, and Medium-High were added. Therefore, samples were actually rated on a 5-point scale (1 = Low; 2 = Medium/Low; 3 = Medium; 4 = Medium/High; 5 = High).
3. Each sound sample was played through PAC64 on a real-time system, listened to over Sennheiser HD-600 headphones. If impairments were obvious, the selection was simply rated. However, if listeners were having difficulty deciding upon a rating the source material was played in order to compare the encoded version to the original.
4. Ratings were individually expressed, and consensus was reached on a final rating for each sound sample. Then, each listener described the specific impairments they heard. These comments were recorded by Greg Nease.
5. In order to ensure that some group choices also would also stress analog transmissions, select sound samples were played through an FM-analog transmission chain (including an Omnia FM audio processor/stereo generator, Rohde and Schwarz laboratory signal generator, coaxial cable, high-end Marantz receiver and Rotel audio pre-amplifier) over high-end speakers. Selections stressing analog are highlighted with an * in Attachment 1.

Final Sound Sample List Selection (Clean-channel Tests)

Sound samples were chosen based on the following criteria:

a. Samples needed to be challenging to digital processing (a minimum ranking of 3), and include specific elements that would stress digital transmission.
b. A reasonable percentage of sound samples needed to be challenging to FM analog processing (these could also be challenging to digital processing),
c. The total group of selections needed to represent a wide range of existing musical styles.

Priority was given to musical samples that were very challenging to both digital and analog processing, and that were representative of normal broadcasting material. Two "critical" samples were also included to highlight specific musical elements (a muted trumpet and the glockenspiel).

Sixteen musical samples and two speech samples[1] were selected.

Selecting Final Sound Sample "Families" (Impaired Laboratory Tests)

Sound samples were grouped together in equivalent "families" (i.e., samples exhibiting the same characteristics). The group consisted of the 16 samples chosen for clean-channel testing and additional samples that were excluded from the final clean-channel list. This list was created solely for compatibility and performance testing in impaired conditions (see **Attachment 3**). Because certain impairment tests require participants to listen to 200+ sound samples, it was felt that severe listener fatigue would occur if the same 2-3 sound samples were repeated 60-100 times. Therefore, where appropriate, equivalent sound samples can be used to minimize the effects of presenting the same stimuli repeatedly.

[1] Two additional speech samples will be selected by iBiquity, and distributed to listeners for approval.

Attachment 1

Sound Sample Selections Recommended to the NRSC

Sound Sample	Description	Degree of Challenge for Digital System	Digital Impairment(s) in 64 kb PAC
Music			
Bach, Brandenburg Concerto (Harpsichord)	Classical Solo Harpsichord and Orchestra	4	Phase distortion, transient distortion (strings), watery
Bizet, Carmen	Orchestra featuring castanets, bells and other percussive instruments	5	Transient distortion, pre-echo distortion (castanets, harp)
Handel Messiah	Choral with Orchestra	5	Overall fidelity; loss of image integrity
1812 Overture*	Orchestra, featuring cannons	3	Percussive transient distortion (cannon)
Kyoko Saito	Female Opera with piano	3	High-frequency distortion (warbling); loss of image integrity
Medewski, Medin and Wood	Jazz Instrumental	5	Smearing; wavering (piano); thin
Trumpet*	Solo trumpet arpeggio (muted)	5	Loss of realism
Glockenspiel*	Critical sample, 4 tones	5	Intermodulation; fuzziness; loss of decay; warbly
Turkish Folk Music	Alternative featuring unusual percussion	4	Loss of high frequencies; loss of realism; loss of detail
Paul Simon, *Can't Run But*	Alternative featuring unusual percussion	4	Loss of definition in percussion; vocal distortion
Amy Grant*, *Baby Baby*	Female Vocal Rock	5	Intermodulation; fuzziness; watery
Earth, Wind and Fire**, Let's Groove*	Rock Instrumental/Choral	5	Dynamic phase distortion; Loss of definition; Watery; Buzzy
Enya	New Age, featuring bass clarinet	4	Loss of realism; Wavering; warbling

Sound Sample	Description	Degree of Challenge for Digital System	Digital Impairment(s) in 64 kb PAC
Eric Clapton, *Change the World*	Male Vocal Rock	4	Vocal roughness; sibilance; background coloration
Randy Travis, *A Little Bitty Crack in her Heart*	Male Vocal Country	5	Vocal distortion; Harsh; Phase distortion; Modulated background
Speech			
English Woman*	Female	5	Vocal distortion; doubling
Sample 2 (tbd)	Female		
Tom Brokaw*	Male	5	Vocal distortion; doubling
Sample 2 (tbd)			

* Stresses analog processing substantially

Attachment 2

Complete Listing of Submissions

	Artist, Album, Sound Track	Description	Digital Rating
1	Castinets (Sqam disc)	Critical Sample	4
2	Fountain Music (from NRSC disc)	Critical Sample	Eliminated without rating (artificial)
3	Tchaikovsky, *1812 Overture*	Classical Instrumental	3
4	Bach, *Brandenburg Concerto*, Presto	Classical Instrumental	5
5	Jeff Beck, *Who Else*, What Mama Said	Rock Instrumental	2
6	Tom Brokaw (The Greatest Generation)	Speech Male vocal	5
7	Bizet's *Carmen*	Classical Instrumental	5
8	Eric Clapton, *Best of Eric Clapton*, Change the World	Rock Male Vocals	4
9	Paula Cole, *Harbinger*, Happy Home	Rock Female Vocal	4
10	Copeland, Rodeo	Classical Instrumental	1
11	Moulton Labs, *Critical Listening Excerpts* CD, (*Bang & Olofsun Test Sequence ,* Robert Cray	Blues/Jazz Male	3
12	Crowded House, *Woodface* , Weather with You	Rock Male vocal	4
13	Crosby, Stills, Nash & Young, *Looking Forward*, Sanibel	Rock Male vocals	5
14	Debussy Quartet	Classical Instrumental	3
15	Earth, Wind & Fire, *Greatest Hits*, Let's Groove	Rock Male vocal	5
16	Donald Fagen, The Nightfly, I.G.Y	Rock Male vocal	4
17	Stravinski, FireBird	Classical Instrumental	3
18	Fleetwood Mac, *Tango in the Night*, Big Love	Rock Mixed vocals	3
19	Glockenspiel (Sqam disc)	Critical Sample	5
20	Amy Grant, *Heart In Motion*: Baby, Baby	Rock Female vocal	5

	Artist, Album, Sound Track	Description	Digital Rating
21	*Critical Listening Excerpts (Bang & Olofsun Test Sequence),* Britten's Young Person's Guide to the Orchestra	Classical Instrumental	Eliminated without rating (poor recording)
22	Handel, *Messiah*, Hallelujah	Classical Choral	5
23	Jacques Ibert, *Summertime Music for Oboe and Guitar*, Entr'acte	Classical Instrumental	3
24	Metallica, The Unforgiven	Rock Instrumental	2
25	Medewski, Medin and Wood, Cut 2	Jazz Instrumental	5
26	Pink Floyd, *Pyramid*, Eclipse	Rock Instrumental	Eliminated without rating (redundant)
27	Prince, *The Hits 1*: Diamonds and Pearls	Rock Male vocal	5
28	REO Speedwagon, *Hi Infidelity*, Keep On Loving You	Rock Male vocal	3
29	Moulton Labs, *Critical Listening Excerpts* CD, cut 3 *(Kyoko Saito)*	Classical Female	3
30	Carlos Santana, *Supernatural*, Smooth	Rock Male vocal	4
31	Shania Twain, *Come On Over*, That Don't Impress Me Much	Rock Female vocal	Eliminated without rating (redundant)
32	Paul Simon, *Rhythm of the Saints,* Can't run but	Rock/Pop Instrumental	4
33	Lisa Stansfield, *Lisa Stansfield*, The Real Thing	Rock Female vocal	1
34	Toni Basil, *VH1 More Of The Big '80s*: Mickey	Rock Female vocal	1
35	Randy Travis, *A Man Ain't Made of Stone*, A little bitty crack in her heart	Country Male vocals	5
36	Suzanne Vega, *Nine Objects of Desire*, Caramel	Rock Female vocal	3
37	Turkish Folk Music	Folk Instrumental	4
38	English Woman speech (Sqam disc)	Female vocal	5
39	Bass Clarinet Arpeggio (Sqam disc)	Single Instrument	5
40	Muted Trumpet (Pictures at an Exhibition)	Single Instrument	5
41	Suzanne Vega with Breaking Glass, Tom's Diner	Female vocal	Eliminated without rating (artificial)
42	Rain and Clarinet (AT&T creation)	Instrumental with sound effects	Eliminated without rating (artificial)

	Artist, Album, Sound Track	Description	Digital Rating
43	Dire Straits	Intro – Instrumental	1
44	Pearl Jam, Daughter	Rock vocals	1
45	Harpsichord arpeggio	Single Instrument	4
46	Enya, Shepard Moons	New Age Instrumental	4
47	The Sundays, I can't wait	Instrumental	3
48	Liszt	Classical Instrumental	Eliminated (poor recording)
49	Tchaikowsky, Nutcracker Suite	Classical Instrumental	Eliminated without rating (redundant)
50	Rolling Triangle	Single instrument	5

Attachment 3

Families of Sound Samples

Family	Sound Samples
Classical Orchestral	**Bach Brandenburg** **Bizet Carmen** **Handel Messiah** **Tschaikovsky 1812** **Stravinski Firebird**
Lightly Processed Mix	**Ibert, Oboe and Guitar** **Debussy Quartet** **Kyoko Saito** **Paul Simon** **Turkish Folk Music** **Enya** **Medewski, Medin, and Wood**
Female Vocals (Rock/Pop)	**Suzanne Vega** **Paula Cole** **Amy Grant*** **Lisa Stansfield** **Toni Basil**
Male Vocals (Rock/Pop)	**Donad Fagen** **Robert Cray** **Randy Travis**
Pop – instrumental/choral	**Earth Wind and Fire** **Crosby, Stills, Nash and Young** **Eric Clapton** **Crowded House** **Prince** **Santana** **Fleetwood Mac** **REO Speedwagon**
Dense Rock	**Jeff Beck** **Metallica**
Single Instrument	**Trumpet** **Glockenspiel**

***To be used for undesired analog modulation**

Appendix B

ATTC Procedures

Appendix C

ATTC Results

Appendix D

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DYNASTAT – AUDIO TESTING METHODS AND PROCEDURES FOR EXPERIMENT RF1

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14 February 2002

INTRODUCTION

Dynastat performed the raw data collection for iBiquity Digital Corporation for the audio subjective testing in experiment **RF1**. Dynastat received digital audio files for 224 conditions from iBiquity, recruited a crew of listeners, presented the materials to the listeners, and delivered the raw data to iBiquity.

SUBJECTIVE TESTING FACILITIES

Dynastat has a Subjective Test Laboratory specifically designed for Audio Testing. The laboratory is contained in a quiet interior room that will accommodate the testing of up to four listeners at a time. Each listener is seated in an individual sound-treated Tremetrics audio testing booth with a measured ambient noise level < 35dBA. Audio samples are presented to listeners binaurally over Sennheiser HD-600 open-backed headphones. The subjective rating scales are displayed on a flat-screen Viewsonic VG150 LCD monitor located on a table opposite the window of each booth and the listeners enter their responses using a PC mouse. The only equipment inside the booth is a chair, a laptop desk, a pair of headphones, and a PC mouse.

Each listening station includes the sound-treated booth, an HP Vectra VL400 PC, a high-quality Lucid DA9624 digital to analog converter, and the Sennheiser headphones. Figure 1 shows two views of listening stations contained in Dynastat's Audio Testing Laboratory. The PC's, A/D converters, and headphones were provided to Dynastat by iBiquity. Sound samples are stored on the hard-disk of each PC and are presented to the listeners under program control using a software package developed by iBiquity. The software also displays the appropriate rating scale(s) on the monitor and collects and stores the listener's responses. Each listening station is independent and self-contained and requires no experimenter control or interaction once the listener has started an experiment. Dynastat's Audio Laboratory includes four listening stations with the individual PC's networked to a server PC used for loading audio files and compiling listener responses.

LISTENER SAMPLE

The sample of listeners for this experiment was stratified both for listener gender and age-group. Listeners were recruited to represent approximately equal representation in eight categories: four *Age-Groups* (16-24, 25-32, 33-42, 43-50) for each *Gender* (male, female). The experiment required Dynastat to deliver the subjective data from 40 *qualified* listeners, where *qualification* was based on performance on an initial screening-test developed by iBiquity and a post-hoc screening test designed to eliminate obvious outliers. To achieve balance in the stratification of the sample and at the same time account for disqualifications due to failures of

the screening-tests, 48 listeners were recruited for this experiment. Listeners were recruited primarily

Fig. 1 Two views of a listening station contained in Dynastat's Audio Testing Laboratory.

from a pool of more than 2000 listeners contained in Dynastat's subjective testing database. This database is a continually evolving and expanding pool of listeners that Dynastat has maintained for use in subjective evaluation of speech-coding and voice-communications systems. Membership in Dynastat's subjective database is largely dictated by guidelines specified by ITU-T[1] and other standardization bodies.

PROCEDURES

Upon arrival at Dynastat, listeners completed a brief biographical data-sheet and received written instructions on the specific tasks to be performed in the experiment. Exhibit A shows the instructions that were provided to the listeners. Each listener was assigned a unique eight-character listener ID (i.e., **Eeesai**) coded for experiment (**Eeee**), gender (**s** = 1 for male, 2 for female), age-group (**a** = 1 for 16-24, 2 for 25-32, etc.), and individual (i.e., individual within the category, **i** = 1, 2, etc.). For example, the ID "RF1x*112*" would identify the 2nd individual listener who was a male listener in age-group 16-25 participating in Experiment RF1. The test administrator entered the listener's ID and biographical information into an Excel *Participant* file specific to the experiment. The overall duration of the experiment was approximately 2 hours and included three phases: a training phase, a screening phase, and a testing phase consisting of

1 ITU-T Recommendation P.800, Methods for subjective determination of transmission quality, Aug., 1996.

four test sessions. The overall test duration is within the maximum testing time recommended by the ITU-T's recommendation P.800.

Training Phase

During the training phase listeners were presented a range of audio impairments typical of those involved in the testing phase of the experiment. The training phase was developed and provided to Dynastat by iBiquity and was used to expose and familiarize the listeners to the variety and range of conditions they were likely to hear in the subsequent screening and testing phases. The impairments presented in the training phase served to train the subjects to listen carefully for potential impairments in the audio samples. The listeners were given written instructions prior to the training phase. Exhibit A shows those written instructions. The training materials were presented to the listeners in the individual listening stations. There were six training trials, each involving two samples. In each training trial, the first sample was a "clean" cut followed by a second sample, an "impaired" cut of the same audio materials. Listeners entered a response using the ACR scale (described in a later section) for each of the two samples within each of the six training trails. The experimenter never discussed the specific types of impairments involved in the training samples or how the listeners should judge or value those impairments.

Screening Phase

Immediately after the training phase, listeners participated in a pre-test screening phase to ensure that they were able to reliably distinguish between "clean" and "impaired" samples. The listener's task in the screening phase was a "Reference-A-B" comparison in which the listener was required to decide which of two "test" samples (A or B) was the same as the reference sample. In each trial one of the test samples was the same as the clean or unimpaired reference sample and the other sample was an impaired sample. Figure 2 shows the PC response display that was used for the screening task. Playback of samples was under the individual listener's control, but the screening software required him to listen to all three samples, reference and two test samples, before the response options were available. Listeners were free to replay any or all of the three samples until they were ready to enter their response and proceed to the next trial. The screening phase consisted of one practice trial and ten test trials. Listeners were provided no feedback on the "correctness" of their responses during the screening test. After completion of the screening phase, the listeners exited their booth for a short rest-break during which the test administrator scored their screening responses. Listeners were not informed of their specific performance in the screening phase, but depending on their score, were allowed to continue in the experiment or were dismissed. If a listener scored less than 80% correct he was paid a partial fee for his participation and was not allowed to proceed to the test phase of the experiment. Listeners who scored 80-100% proceeded to the test phase as a "qualified" listener and their

rating data was used in "post-hoc" screening designed to provide the most reliable data possible. Description of the "post-hoc" data screening is provided in a later section.

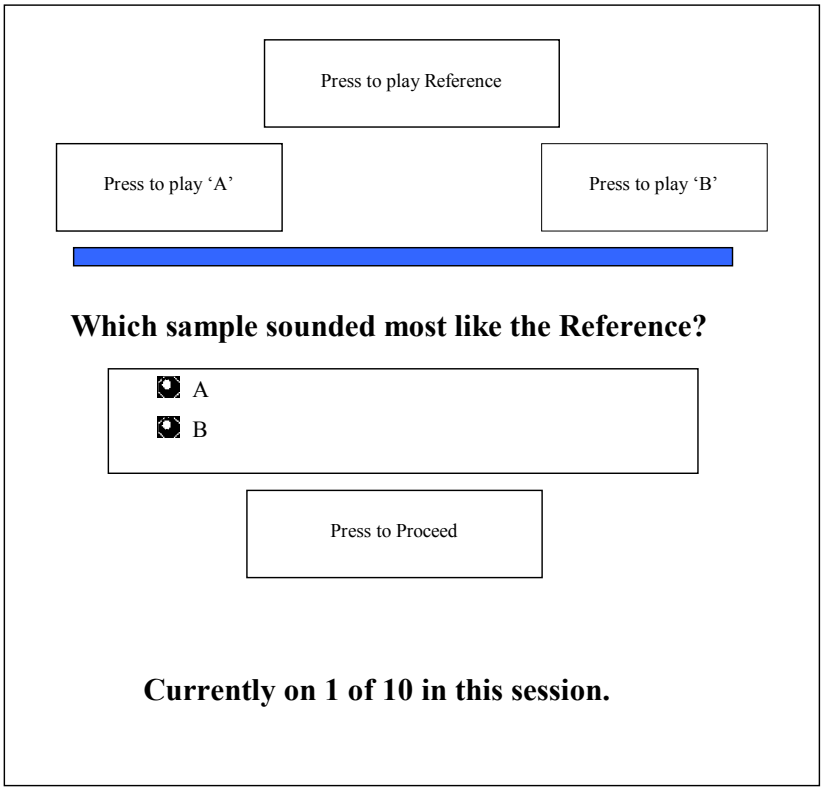

Fig.2 Response display for the Ref/A/B task in the screening phase.

Testing Phase

The Absolute Category Rating (ACR) method was used in this experiment to evaluate the subjective quality of the audio conditions. The ACR yields the Mean Opinion Score (MOS), a measure of overall audio quality. The ACR requires the listener to judge the quality of an audio sample using a five category rating scale where: Excellent=5, Good=4, Fair=3, Poor=2, and Bad=1. The category judgments are reported as a measure of overall audio quality, or MOS, on a scale of 1 to 5. A response display for the ACR testing task is shown in Fig. 3. The listener controlled playback of the audio samples but on each trial he could enter his response only after listening to the entire sample. The testing phase consisted of two practice trials followed by 224 test trials. The listener could adjust the playback volume during the practice trials. The playback volume set by the listener during the practice trials was then maintained throughout the remainder of the experiment. Test trials were grouped into four sessions of 56 trials each, separated by rest-breaks. During the rest-breaks listeners were required to remove the headphones and leave the booth.

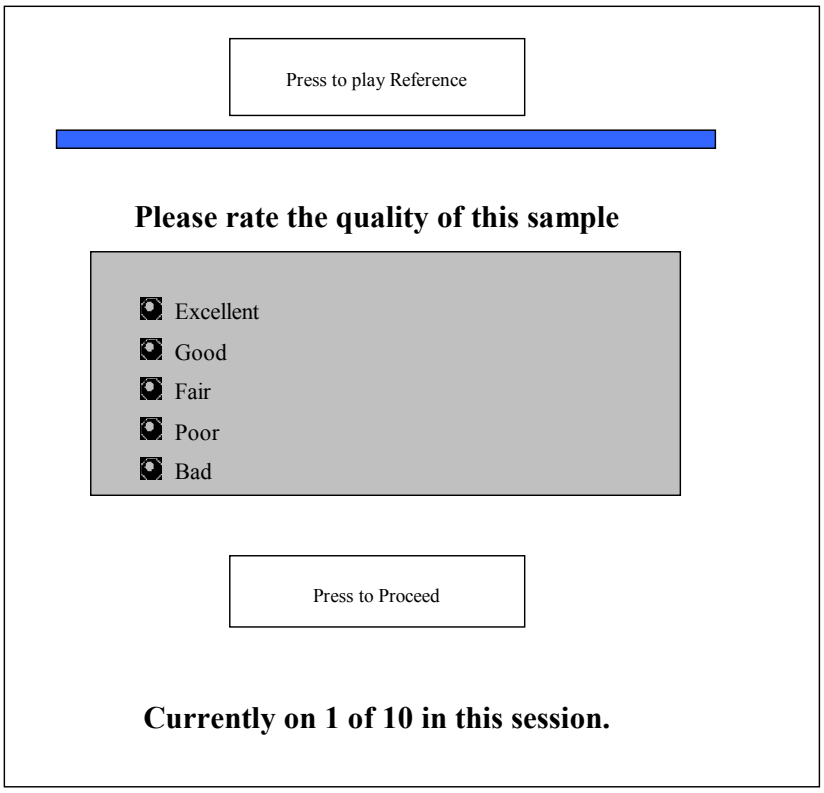

Fig. 3. Response display for the ACR task in the testing phase.

AUDIO MATERIALS

For this experiment 224 processed audio samples were supplied to Dynastat by iBiquity via Internet FTP. The files were provided in digital format (44.1KHz, 16 bit linear WAV). The digital files were loaded onto the hard-disk of the server PC and then distributed to the hard-disks of the individual PC's though a local area network.

AUDIO FILE PRESENTATION AND DATA COLLECTION

Dynastat prepared an Excel file that controlled the audio file presentation and data collection software. During this process the audio files were loaded and verified, file order randomizations were created, and the overall layout of the experiment was established (i.e., number of test sessions, number of trials per session, and number of rest-breaks). The iBiquity software package automatically accumulated the listener responses into an Excel *Response* spreadsheet. Once a test session had been initiated, the iBiquity software required no input from the test administrator. File presentation and data collection were controlled by the interaction of the listener and the software.

POST-HOC DATA ANALYSIS AND LISTENER SCREENING

At the conclusion of the raw data collection, the total set of listener data (i.e., the *Response* Excel file) was subjected to a post-hoc analysis to ensure the validity and the reliability of the data for each individual listener. A "Figure of Merit" (FoM) was calculated for each listener participating in the experiment. The FOM was the "coefficient of correlation" between the individual listener's vector of ratings and the vector containing the average ratings for the remainder of the listeners involved in the experiment. Thirty years of experience with subjective rating data has shown this FoM to be a valuable screening measure to remove clear "outliers" from the rating data (i.e., listeners who either can't or won't perform the rating task). A practical lower threshold for the identification of "outliers" is derived empirically from the data. Since the FoM is based on a correlation coefficient, it is largely determined by the range and variation in the experimental conditions. The threshold FoM for experiment RF1 was .380.

DATA DELIVERY

Dynastat compiled and delivered two Excel workbooks to iBiquity. The *Participant* workbook contained biographical and ID information. One worksheet within the Participant workbook contained the ID information for the 40 listeners retained in the final data set; a second worksheet contained the ID information for the 8 listeners removed from the final data set. The *Response* workbooks contained corresponding worksheets, each containing the raw response data for the two sets of listeners. Exhibit B shows the Participant worksheet for experiment RF1.

Exhibit A - Instructions for Experiment RF1

Training Phase

Prior to the actual tests you will have a training session. The purpose of the training session is to help you establish a personal reference for rating the audio samples. The format of the training session is exactly the same as the actual test. You will be asked to grade the samples on a 5-point quality scale. The training session consists of six pairs of samples (a total of 12 samples). In each pair the audio is the same, however, the first sample will be of high quality and the second sample will be of lesser impaired quality.

Testing Phase

Overview

Welcome to this audio testing session. Today, you will be participating in a listening experiment which should last about two and a half hours. You will be listening to music and speech samples over headphones. We are studying how various radios sound under different transmission conditions. There are three parts to this study. The first part is training, where you will listen to the music you will be encountering in your tests. The second part is a discrimination test. The third part is an opinion test.

Training Task

In the training session, you will hear a variety of sound samples. These sound samples include typical transmission "impairments" you might hear during the discrimination and opinion tests. These impairments should be noticeable. During the course of each sample you will hear varying degrees of the "impairment". You will indicate to the administrator if differences are heard.

Discrimination Task

In the discrimination task we will be testing your ability to hear different impairments. In this task your job is to decide which of two samples (A or B) is most nearly the same as the reference sample. The response display is shown in Fig. 1. To begin click on the box labeled "Press to Play Reference". The complete reference sample will be played. Similarly, you will click on "Press to Play A" and "Press to Play B" to play these complete samples. The program will not let you enter a response until you have heard all three samples completely. After listening to the complete Reference, A, and B samples you can enter your response to the question "Which sample sounded most like the reference?". After indicating your response click on the box labeled "Press to proceed". If you would like to play any of the samples again, you can press the appropriate box and do so as much as needed until you have made your decision. Once you have indicated your response and clicked on the "Press to proceed" you will be ready to start your next trial. During the course of your practice trial for this task you can set the volume level my moving the slider box. Once this level is set it cannot be changed for the rest of the session.

The discrimination session will consist of one practice trial and 10 test trials. When you complete the task open the door and proceed to the waiting room for a 10-minute break. During the break the administrator will score your data and let you know if you passed the test. If you passed the test then you are eligible to participate in the opinion test. If you did not pass you will be paid $20 for your efforts.

Opinion Task – The ACR-MOS Test

In this part of the experiment we are evaluating systems that might be used for the radio transmission of sound samples. You are going to hear a number of recorded samples and rating how good you think they sound.

On each trial a single sample will be presented. Each sample will consist of a 10-15 second music or voice passage. Please listen to the complete sample, then indicate your opinion of the overall sound quality of the sample using the following 5-point scale: Exellent, Good, Fair, Poor, Bad. Figure 3 shows the response display.

This task is different from the discrimination task. There is no stated reference against which to compare the samples you are hearing. You simply hear a passage and then make a rating. You will have to use an internal reference to judge ‘‘the goodness’’ of the sample. By that we mean, when you are listening to a particular sample, think about how a very good radio station would sound in your car and over your home radio. Judge the sample in relation to your memory of those two references.

Many things go into a quality rating. You’ll be listening for impairments as well as the overall aesthetic quality. By aesthetic we mean beauty, musicality, character, sound quality, etc. Try to judge each sample in an overall sense. This is especially hard to do if a big impairment happens to occur at the end of the sample. So, before you rate each sample, take a few seconds to think about the entire sample you just heard. In that way, it won’t be just your last impression that carries the most weight.

The experiment will involve four test sessions separated by short rest periods. In the first session you will have a practice block of 2 trials to familiarize you with the rating task and adjust your listening volume. The practice block will be followed by 4 test sessions of 50 trials each. If you have any questions, please feel free to ask the test administrator.

Please do not discuss your opinions with any other listeners participating in the experiment. Thank you in advance for your participation.

Exhibit B

Participant Worksheets for Experiment RF1.

40 Listeners Retained in Final Data Set

Experiment Code	Sex	Age Group	FoM	Experiment Code	Sex	Age Group	FoM
RF1x111	Male	1	0.655	RF1x211	Female	1	0.521
RF1x112	Male	1	0.658	RF1x213	Female	1	0.529
RF1x113	Male	1	0.449	RF1x214	Female	1	0.502
RF1x114	Male	1	0.596	RF1x215	Female	1	0.654
RF1x115	Male	1	0.509	RF1x216	Female	1	0.664
RF1x121	Male	2	0.552	RF1x217	Female	1	0.552
RF1x122	Male	2	0.657	RF1x221	Female	2	0.672
RF1x123	Male	2	0.615	RF1x222	Female	2	0.578
RF1x124	Male	2	0.705	RF1x224	Female	2	0.505
RF1x125	Male	2	0.530	RF1x225	Female	2	0.415
RF1x126	Male	2	0.382	RF1x226	Female	2	0.643
RF1x131	Male	3	0.506	RF1x232	Female	3	0.372
RF1x132	Male	3	0.520	RF1x234	Female	3	0.427
RF1x133	Male	3	0.525	RF1x235	Female	3	0.454
RF1x134	Male	3	0.601	RF1x236	Female	3	0.435
RF1x135	Male	3	0.734	RF1x237	Female	3	0.600
RF1x136	Male	3	0.491	RF1x241	Female	4	0.415
RF1x142	Male	4	0.525	RF1x243	Female	4	0.570
RF1x143	Male	4	0.380	RF1x244	Female	4	0.478
RF1x144	Male	4	0.401	RF1x246	Female	4	0.579

8 Listeners Deleted from Final Data Set

Experiment Code	Sex	Age Group	FoM
RF1x116	Male	2	0.255
RF1x145	Male	4	0.299
RF1x146	Male	4	0.266
RF1x212	Female	1	0.466
RF1x231	Female	3	0.333
RF1x233	Female	3	0.299
RF1x242	Female	4	0.363
RF1x245	Female	4	0.318

Appendix E

FM IBOC DAB
Laboratory Test I
Subjective Evaluation Results

February 18, 2002

iBiquity Digital Corporation

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Sound Samples		CD	Gen2	Delphi	Technics	Pioneer	Sony
1812	MOS	3.95	4.13	3.75	3.35	3.45	3.25
	C/I (+/-)	0.26	0.30	0.30	0.32	0.28	0.35
Bach	MOS	4.38	4.43	4.23	4.33	4.18	4.18
	C/I (+/-)	0.27	0.26	0.29	0.26	0.30	0.31
Brokaw	MOS	4.08	4.23	4.20	3.90	4.10	3.38
	C/I (+/-)	0.26	0.27	0.27	0.35	0.27	0.34
Carmen	MOS	4.65	4.70	4.40	4.50	4.40	4.58
	C/I (+/-)	0.22	0.20	0.24	0.24	0.26	0.21
Clapton	MOS	4.75	4.63	4.70	4.58	4.55	4.68
	C/I (+/-)	0.15	0.19	0.18	0.24	0.24	0.19
Earth Wind And Fire	MOS	4.15	4.15	4.13	4.10	4.15	3.78
	C/I (+/-)	0.37	0.31	0.32	0.34	0.33	0.39
English Male	MOS	4.50	4.65	4.50	4.30	4.43	4.23
	C/I (+/-)	0.23	0.23	0.21	0.24	0.24	0.25
Enya	MOS	4.23	4.20	3.88	3.83	3.80	3.53
	C/I (+/-)	0.29	0.29	0.35	0.27	0.31	0.38
Glock	MOS	4.73	4.68	4.40	4.60	4.30	4.13
	C/I (+/-)	0.18	0.19	0.25	0.21	0.25	0.33
Grant	MOS	4.55	4.48	4.48	4.45	4.35	4.23
	C/I (+/-)	0.19	0.21	0.23	0.21	0.25	0.25
Handel Messiah	MOS	4.30	4.28	4.05	4.20	4.00	3.95
	C/I (+/-)	0.23	0.21	0.31	0.28	0.26	0.32
MMW	MOS	4.48	4.38	4.50	4.30	4.10	4.28
	C/I (+/-)	0.23	0.27	0.25	0.28	0.30	0.31
Saito	MOS	4.63	4.55	3.70	3.75	3.65	3.50
	C/I (+/-)	0.19	0.18	0.31	0.34	0.32	0.24
Persian	MOS	4.48	4.55	4.23	4.20	4.35	4.13
	C/I (+/-)	0.25	0.29	0.28	0.29	0.25	0.32
Travis	MOS	4.68	4.48	4.18	4.20	4.38	3.93
	C/I (+/-)	0.19	0.20	0.29	0.32	0.25	0.33
Trumpet	MOS	4.23	4.30	3.68	3.78	3.40	3.98
	C/I (+/-)	0.28	0.36	0.42	0.21	0.43	0.35
Simon	MOS	4.60	4.50	4.35	4.43	4.30	4.20
	C/I (+/-)	0.17	0.23	0.25	0.27	0.33	0.30
English Woman	MOS	4.10	4.13	4.15	3.98	3.80	3.78
	C/I (+/-)	0.27	0.30	0.27	0.29	0.33	0.35
Debussy	MOS	4.78	4.83	4.40	4.58	4.50	4.40
	C/I (+/-)	0.15	0.14	0.24	0.21	0.23	0.22
Fagen	MOS	4.60	4.63	4.55	4.48	4.40	4.48
	C/I (+/-)	0.21	0.23	0.21	0.24	0.24	0.24
Ibert	MOS	4.60	4.45	4.13	4.13	4.23	4.08
	C/I (+/-)	0.21	0.21	0.25	0.25	0.22	0.27

Sound Samples		CD	Gen2	Delphi	Technics	Pioneer	Sony
REO	MOS	4.13	4.00	3.85	4.00	4.03	3.98
	C/I (+/-)	0.28	0.30	0.33	0.32	0.27	0.30
Stansfield	MOS	4.53	4.55	4.03	4.23	4.00	3.98
	C/I (+/-)	0.24	0.22	0.33	0.25	0.26	0.27
Vega	MOS	4.55	4.53	4.45	4.55	4.43	4.20
	C/I (+/-)	0.22	0.28	0.25	0.22	0.22	0.25
Crowded House	MOS	4.63	4.60	4.50	4.60	4.55	4.53
	C/I (+/-)	0.19	0.21	0.18	0.17	0.18	0.20
Stravinski	MOS	4.65	4.70	4.45	4.38	4.50	4.43
	C/I (+/-)	0.19	0.21	0.24	0.22	0.23	0.21
Fleetwood	MOS	4.45	4.63	4.45	4.40	4.55	4.40
	C/I (+/-)	0.21	0.21	0.24	0.24	0.21	0.25
Cole	MOS	4.55	4.70	4.48	4.48	4.53	4.43
	C/I (+/-)	0.19	0.18	0.18	0.23	0.21	0.21
CSNY	MOS	4.50	4.58	4.53	4.48	4.55	4.60
	C/I (+/-)	0.21	0.21	0.23	0.24	0.19	0.19
Santana	MOS	4.33	4.53	4.18	4.30	3.98	4.00
	C/I (+/-)	0.27	0.25	0.24	0.28	0.31	0.28
Toni Basil	MOS	4.38	4.58	4.35	4.35	4.45	4.25
	C/I (+/-)	0.25	0.21	0.27	0.23	0.19	0.25

Appendix F

FM IBOC Digital Quality
Subjective Evaluation Data Analysis

February 18, 2002

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1. Introduction

The Unimpaired Audio Quality Test was designed to assess the hypothesis that consumers judge the audio quality of iBiquity's FM IBOC system to be qualitatively better than the current analog FM broadcast system operating under ideal "clean channel" conditions. The test also was designed to test whether the FM IBOC system delivers audio quality equivalent to that of a compact disc (CD) audio.

2. Test Methodology

The Unimpaired Audio Quality Test used the Absolute Category Rating Mean Opinion Score (ACRM) methodology. In the ACRM, participants judge sound samples on an individual basis, using an implicit reference to judge the quality of the sound sample. Within a particular ACR experiment, participants generally hear a variety of sound samples that may differ on several dimensions. By presenting the samples in this manner, individual transmissions are judged on their own merit in an absolute sense. The participant mission is to give a statement of overall quality for each sound sample, taking into consideration the variety of audio elements that may be present.

The ACRM testing methodology is particularly suitable for measuring overall system performance and consumer appreciation of a particular technology or system. Because the differences between the systems being tested were anticipated to be small, iBiquity undertook a statistical analysis to provide greater confidence in the results. Established statistical tools for analyzing the data can increase the precision of differential comparisons and allow conclusions to be reached with a high degree of confidence.

3. Summary of Test Results

Table F-1 shows the average MOS score for each system over all the 18 audio samples tested. The averages scores show that the FM IBOC system performs better than the 4 analog receivers. Moreover, the averages show that the audio quality of the Gen 2 IBOC system is equal to that of the CD reference.

CD	FM IBOC	Delphi	Pioneer	Technics	Sony
4.41	4.41	4.19	4.09	4.15	3.98

Table F-1 System MOS Averages

4. Statistical Comparison of Systems

The results in this section show that the FM IBOC system, under clear channel conditions, (i) delivers audio which is noticeably superior to any of the analog receivers under test (Delphi, Pioneer, Technics, and Sony) and (ii) delivers CD-quality audio.

The average MOS score for each audio sample of the FM IBOC system is compared to the corresponding sample for each Test System (CD reference, Delphi, Pioneer, Technics, and Sony) in order to *statistically determine for each sample whether the FM IBOC system is equivalent to, better than or worse than the Test System*. The actual statistical hypothesis testing method is described in Section 5. The results and conclusions are summarized below in Table F-2.

This analysis indicates that the MOS rating of the FM IBOC system ***is statistically equivalent*** to that of the CD reference for 17 audio samples. FM IBOC performs worse for one sample (Travis). Thus, one may confidently infer from the data that the FM IBOC system is equivalent in quality to the high fidelity CD reference.

The FM IBOC system is equivalent in quality to the Delphi and Pioneer receivers for 9 of the 18 audio samples and ***outperforms the Delphi and Pioneer*** for the remaining 9 audio samples. The FM IBOC system is equivalent in quality to the Technics receivers for 7 of the audio samples. At the same time, the FM IBOC system ***outperformed the Technics*** for 11 of the samples. Finally, the FM IBOC system ***outperformed the Sony*** receiver for 15 of the 18 samples, and was tied for 3 samples.

In conclusion, the FM IBOC system significantly outperformed each analog receiver for 50% or more of the test samples, and provided an audio quality that was at least equivalent for the remaining samples. At the same time, the audio quality of FM IBOC receiver is statistically equivalent to that of the CD quality. ***This clearly indicates that in terms of unimpaired audio quality, FM IBOC system provides a substantial upgrade in audio quality as compared to analog FM.***

Test System	# of audio samples FM IBOC EQUIVALENT to Test System	# of audio samples FM IBOC BETTER than Test System	# of audio samples FM IBOCWORSE than Test System
CD	17	0	1
Delphi	9	9	0
Pioneer	9	9	0
Technics	7	11	0
Sony	3	15	0

Table F-2: Summary of hypothesis tests of FM IBOC vs. Test System for 18 audio samples at 90% confidence

5. Description of the Statistical Analysis Technique: Hypothesis Testing on Difference of Means

Table A2 below shows the average ACR-MOS scores for each sound sample tested on the various systems for 40 listeners. We shall compare the average MOS score of each sample for the FM IBOC system against the CD reference and the 4 analog receivers. Based on the data available one can make one of the following hypotheses:

- Hypothesis 0: $\mu_{\text{FM IBOC}} = \mu_{\text{test system}}$
  - The average MOS score of the FM IBOC system is equal to that of the test system. Therefore, the FM IBOC system and the test system are of equal audio quality.
- Hypothesis 1: $\mu_{\text{FM IBOC}} > \mu_{\text{test system}}$
  - The average MOS score of the FM IBOC system is greater than that of the test system. Therefore the FM IBOC system is of higher audio quality than that of the test system.
- Hypothesis 2: $\mu_{\text{FM IBOC}} < \mu_{\text{test system}}$
  - The average MOS score of the FM IBOC system is lower than that of the test system. Therefore, the FM IBOC system is of lower audio quality than that of the test system.

A t-statistic with a 90% confidence level is used to test these hypotheses. The results of the hypothesis tests are shown in Tables A1 through A5 for FM IBOC vs. CD, FM IBOC vs. Delphi, FM IBOC vs. Pioneer, FM IBOC vs. Technics, and FM IBOC vs. Sony, respectively.

Table A1: Results of Hypothesis Test for FM IBOC vs. CD Reference (1 = true, 0 = false)

Sound Sample	H0 $\mu_{FM\ IBOC} = \mu_{CD}$	H1 $\mu_{FM\ IBOC} > \mu_{CD}$	H2 $\mu_{FM\ IBOC} < \mu_{CD}$
1812.wav	1	0	0
Bach.wav	1	0	0
Brokaw.wav	1	0	0
Carmen.wav	1	0	0
Clapton.wav	1	0	0
Earth Wind And Fire.wav	1	0	0
English Male.wav	1	0	0
Enya.wav	1	0	0
Glock.wav	1	0	0
Grant.wav	1	0	0
Handel Messiah.wav	1	0	0
Mmw.wav	1	0	0
Persian.wav	1	0	0
Saito.wav	1	0	0
Simon.wav	1	0	0
Travis.wav	0	0	1
Trumpet.wav	1	0	0
Woman.wav	1	0	0
Total	**17**	**0**	**1**

Table A2: Results of Hypothesis Test for FM IBOC vs. Delphi (1 = true, 0 = false)

Sound Sample	H0 $\mu_{FM\ IBOC} = \mu_{Delphi}$	H1 $\mu_{FM\ IBOC} > \mu_{Delphi}$	H2 $\mu_{FM\ IBOC} < \mu_{Delphi}$
1812.wav	0	1	0
Bach.wav	1	0	0
Brokaw.wav	1	0	0
Carmen.wav	0	1	0
Clapton.wav	1	0	0
Earth Wind And Fire.wav	1	0	0
English Male.wav	1	0	0
Enya.wav	0	1	0
Glock.wav	0	1	0
Grant.wav	1	0	0
Handel Messiah.wav	0	1	0
Mmw.wav	1	0	0
Persian.wav	0	1	0
Saito.wav	0	1	0
Simon.wav	1	0	0
Travis.wav	0	1	0
Trumpet.wav	0	1	0
Woman.wav	1	0	0
Total	**9**	**9**	**0**

Table A3: Results of Hypothesis Test for FM IBOC vs. Technics (1 = true, 0 = false)

Sound Sample	H0 $\mu_{FM\ IBOC} = \mu_{Technics}$	H1 $\mu_{FM\ IBOC} > \mu_{Technics}$	H2 $\mu_{FM\ IBOC} < \mu_{Technics}$
1812.wav	0	1	0
Bach.wav	1	0	0
Brokaw.wav	0	1	0
Carmen.wav	0	1	0
Clapton.wav	1	0	0
Earth Wind And Fire.wav	1	0	0
English Male.wav	0	1	0
Enya.wav	0	1	0
Glock.wav	1	0	0
Grant.wav	1	0	0
Handel Messiah.wav	1	0	0
Mmw.wav	1	0	0
Persian.wav	0	1	0
Saito.wav	0	1	0
Simon.wav	1	0	0
Travis.wav	0	1	0
Trumpet.wav	0	1	0
Woman.wav	1	0	0
Total	**7**	**11**	**0**

Table A4: Results of Hypothesis Test for FM IBOC vs. Pioneer (1 = true, 0 = false)

Sound Sample	H0 $\mu_{FM\ IBOC} = \mu_{Pioneer}$	H1 $\mu_{FM\ IBOC} > \mu_{Pioneer}$	H2 $\mu_{FM\ IBOC} < \mu_{Pioneer}$
1812.wav	0	1	0
Bach.wav	0	1	0
Brokaw.wav	1	0	0
Carmen.wav	0	1	0
Clapton.wav	1	0	0
Earth Wind And Fire.wav	1	0	0
English Male.wav	0	1	0
Enya.wav	0	1	0
Glock.wav	0	1	0
Grant.wav	1	0	0
Handel Messiah.wav	0	1	0
Mmw.wav	0	1	0
Persian.wav	1	0	0
Saito.wav	0	1	0
Simon.wav	1	0	0
Travis.wav	1	0	0
Trumpet.wav	0	1	0
Woman.wav	0	1	0
Total	**7**	**11**	**0**

Table A5: Results of Hypothesis Test for FM IBOC vs. Sony (1 = true, 0 = false)

Sound Sample	H0 $\mu_{FM\ IBOC} = \mu_{Sony}$	H1 $\mu_{FM\ IBOC} > \mu_{Sony}$	H2 $\mu_{FM\ IBOC} < \mu_{Sony}$
1812.wav	0	1	0
Bach.wav	0	1	0
Brokaw.wav	0	1	0
Carmen.wav	1	0	0
Clapton.wav	1	0	0
Earth Wind And Fire.wav	0	1	0
English Male.wav	0	1	0
Enya.wav	0	1	0
Glock.wav	0	1	0
Grant.wav	0	1	0
Handel Messiah.wav	0	1	0
Mmw.wav	1	0	0
Persian.wav	0	1	0
Saito.wav	0	1	0
Simon.wav	0	1	0
Travis.wav	0	1	0
Trumpet.wav	0	1	0
Woman.wav	0	1	0
Total	**3**	**15**	**1**

References

1) Dynastat Report
2) Hogg, R.V. and Tanis, E.A., Probability and Statistical Inference 2nd Edition, MacMillan Publishing Inc., 1983.